air and resuspended in 0.2 ml of distilled water and hydrolyzed overnight at 50°C with 2 ml of NCS tissue solubilizer (Amersham/Searle). To the hydrolyzed sample was added 20 ml of toluene-based counting fluid (PPO-POPOP) and the radioactivity was determined.
64. L. Shimkets and M. Dworkin, unpublished results.
65. R. M. Macnab and D. E. Koshland, Jr., *Proc. Natl. Acad. Sci. U.S.A.* **69**, 2509 (1972); D. A. Brown and H. C. Berg, *ibid.* **71**, 1388 (1974).
66. J. T. Bonner, D. S. Barkley, E. M. Hall, T. M. Konijn, J. W. Mason, G. O'Keefe III, P. B. Wolfe, *Dev. Biol.* **20**, 72 (1969).
67. Studies of chemical signaling would be greatly aided by a chemotactic assay system. The rate of gliding movement of *M. xanthus*, however, is rather low (about 1 μm/min) in comparison to chemotactic movement by other organisms. It is thus difficult to maintain a stable gradient of the chemotactic agent for a sufficient period of time to allow a clearly defined response.
68. K. B. Raper, *J. Elisha Mitchell Sci. Soc.* **56**, 241 (1940); P. Pan, J. T. Bonner, H. J. Wedner, C. W. Parker, *Proc. Natl. Acad. Sci. U.S.A.* **71**, 1623 (1974).
69. I. Takeuchi, in *Nucleic Acid Metabolism, Cell Differentiation and Cancer Growth*, E. V. Cowdry and S. Seno, Eds. (Pergamon, New York, 1969), p. 297; J. T. Bonner, T. W. Siega, E. M. Hall, *J. Embryol. Exp. Morphol.* **25**, 457 (1971); J. H. Gregg, *Dev. Biol.* **26**, 478 (1971); P. A. Farnsworth and L. Wolpert, *Nature (Lond.)* **231**, 329 (1971); Y. Maeda and M. Maeda, *Exp. Cell Res.* **84**, 88 (1974).
70. M. Sussman, in *Curr. Top. Dev. Biol.* **1**, 61 (1966); D. Garrod and J. M. Ashworth, in *Microbial Differentiation*, 23rd Symposium, Society of General Microbiology, J. Ashworth and J. E. Smith, Eds. (Cambridge Univ. Press, London, 1974), p. 407.
71. A. Glücksmann, *Biol. Rev. (Camb.)* **26**, 59 (1951); J. W. Saunders, *Science* **154**, 604 (1966); A. R. Sheldrake, *Nature (Lond.)* **250**, 381 (1974); J. T. Bonner, *On Development* (Harvard Univ. Press, Cambridge, Mass., 1974).
72. S. Sudo and M. Dworkin, *J. Bacteriol.* **110**, 236 (1972); G. Haskå, *Physiol. Plant.* **31**, 252 (1974).

73. We thank H. Reichenbach for Figs. 1 to 4, and J. Zissler and D. Kaiser for many helpful discussions. This work was supported by an NIH postdoctoral fellowship to J.W.W. and NIH grant GM-0687-5254-02 to M.D.

Distributive Computer Networking: Making It Work on a Regional Basis

Effective sharing through a network requires new management and resource distribution techniques.

Ronald W. Cornew and Philip M. Morse

Recent articles in *Science* have dealt with computer networking from a number of perspectives: the national overview for computer and information networks (*1*), the results of free access on an individual campus (*2*), and whether or not an academic computing center should join a network (*3*). In this article we examine the experience of establishing and operating a multisupplier or "distributive" computer network (*4*) and indicate some of the management and resource distribution techniques which the New England Regional Computing Program (NERComP) is finding useful in achieving effective resource sharing on a regional basis. Established in 1971, the NERComP network now serves educational and research computing needs at approximately 40 colleges and universities throughout the six New England states.

The NERComP network is currently unique; it is the only educationally oriented regional network involving multiple supplying institutions which is not contained within a single state or operated by a single quasi-state agency. Its success in achieving a nonsubsidized and completely cost-recovering operation appears particularly relevant to the larger task of establishing such facilities on a national basis, as discussed by Greenberger *et al.* (*1*), Massy (*3*), and others.

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Evolution of NERComP

The New England Regional Computing Program developed from a consortium of New England colleges and universities which, through an IBM grant beginning in 1957, was permitted to use the Model 704 computer located at the Massachusetts Institute of Technology. At that time the MIT computer represented the sole computing resource for these schools. As campus computing proliferated in the early 1960's, many of these institutions began to acquire other sources including, in a growing number of cases, on-campus computers. They continued to make use of the MIT facility, however, because it offered access to a succession of bigger, more capable machines than their own.

By 1967 it was apparent that these colleges and universities, of which more than one-half by then had their own computers, needed a variety of additional services which could not be provided by MIT alone. As they moved toward other suppliers, it became evident that a unified means of accessing the numerous large machines which were then available at academic institutions elsewhere in New England could be very useful. It was this realization that first led to consideration of a network in the region.

In order to prepare its participating institutions for the changes required in accessing a computer by utilizing a network, the consortium, with National Science Foundation assistance, engaged in a number of regional "pump priming" activities in 1968 and 1969. These included a teletype loan program in which a computer terminal and a small supplementary grant were made available to participating schools—typically smaller institutions or those lacking computer resources—to encourage them to try time sharing. The grant was intended to offset most of the costs, including computer charges and long-distance telephone toll charges, for a period of direct connection to one or more of the systems then existing in the region. For some of the medium-sized to larger institutions in New England, the consortium also participated in computer evaluation studies designed to help the institution select equipment that would meet current needs but still be consistent with future network development.

NERComP was incorporated in 1970 as a not-for-profit corporation under the laws of Delaware, which permit formation of a corporation of corporations—a step believed necessary in order to reflect adequately the organizational nature of the consortium. Approximately 40 New England institutions of higher learning participated in the incorporation of the organization. Responsibility to its member institutions was assured through a body of institutional representatives appointed by the presidents of the dues-paying member colleges and universities. These representatives have since met at least once a year. Between general meetings, the business of the organization has been directed by a 12-member board of trustees who are elected by the institutional representatives and who serve staggered, 3-year terms. The president of the company, a salaried officer responsible for implementation of the program, was appointed to head a staff responsible for its day-to-day activities.

Current Network Facility

By 1971, while experimenting under a continuing NSF grant to determine the educational services required by users of a multicomputer network, NERComP was ready to make its first attempt at operating a network. A regional facility, centered at NERComP's office in Cambridge, Massachusetts, became operational in that year and has now linked together the seven computer centers depicted in Fig. 1.

There are four main reasons why NERComP originally chose a multisupplier or distributive network.

1) A history of cooperation in computing among the participating institutions encouraged ambitious resource sharing goals.

2) A growing number of faculty at the smaller schools with little or no exposure to computing were eager to employ the computer in their classes without having to acquire extensive programming knowledge (a step made possible by increased access to the application programs already in existence at the major computer centers in the region).

3) The growth of specialized data based systems, such as Dartmouth's IMPRESS, added impetus to the desire of individuals at member institutions of all sizes to use multiple computing facilities.

4) With long-term load sharing the discontinuous growth of individual computer centers (necessitated by the large incremental changes in machine capabilities even within a single product line) could be smoothed by temporarily accessing remote facilities.

There never was significant interest in having NERComP establish a large central facility in an attempt to service all member needs; computing in the region was already too well developed for that and no one had any illusions that a single system could meet all needs, least of all the computer center directors who lived with the inadequacies of existing systems on a day-to-day basis.

The initial data communications network selected was a line-switching system linking users with suppliers through a switching facility located at the NERComP central office. Here the term "line-switching" refers to a telephone line connection made by physically connecting an incoming line with an appropriate outgoing line through a special switchboard or network control unit (NCU). Each user's terminal is connected to a data set (or an acoustic coupler) which is used to dial into another data set in his own locality. This second set is directly connected to a frequency division multiplexor, which in turn simultaneously transmits several data streams from other users in the same area over individual channels on a leased telephone line to a receiving multiplexor in NERComP's central switching office. There the user is connected through the central line-switcher to another multiplexor which transmits over leased lines to the supplying computer center in the same manner, with connection to this "host" computer being the ultimate result. The connection so established is bidirectional, allowing the computer to respond to the user over the same lines (see Fig. 2).

The NCU can function in either a manual or automatic mode. When a user initiates a call, his terminal is either connected to a programmed computer port, or it triggers an alarm answered by a human operator at a control terminal attached to the NCU. The operator can both send and receive messages between any user or computer and can connect the user to any available machine. Initially, users accessed the network through terminals with speeds of 10 and 30 characters per second, although facilities for higher-speed termi-

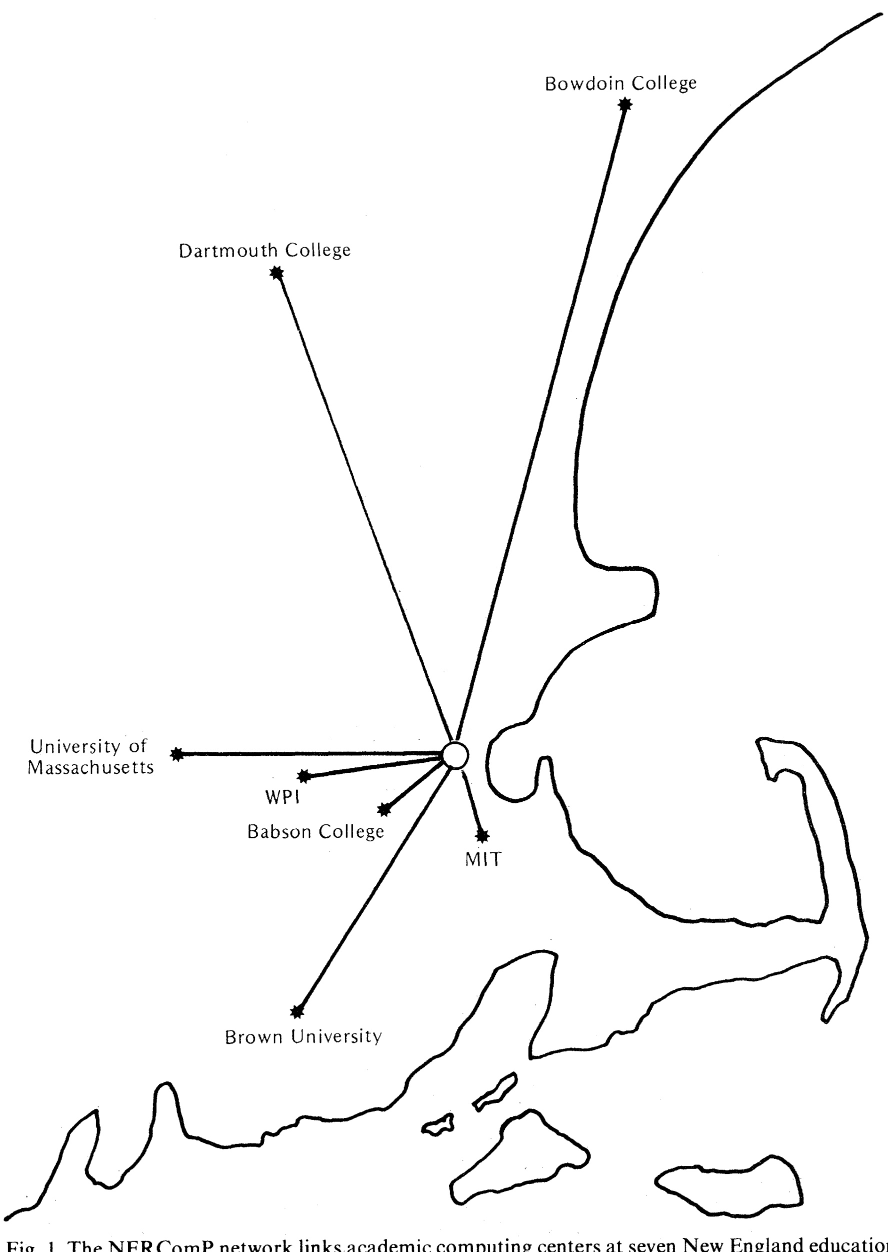


Fig. 1. The NERComP network links academic computing centers at seven New England educational institutions: Bowdoin College (PDP-10 computer), Dartmouth College (H635 dual processing system), University of Massachusetts (Cyber 74-18), Worcester Polytechnic Institute (PDP-10), Babson College (HP2000C), Brown University (System 360 Model 67), and the Massachusetts Institute of Technology (System 370 Model 168). Connections to user institutions have been omitted in this illustration.

nals, including remote job entry stations for batch processing, have subsequently been added.

By late 1973 this network had achieved a level of usage which allowed complete cost recovery. Operationally, NERComP purchased in bulk from its suppliers at wholesale rates, while distributing through the network to its member institutions at retail prices comparable to those prevailing on supplier campuses. All user billing has been handled through the NERComP central office, with the organization in turn compensating the supplying centers. While NERComP has subsequently received grant funding to subsidize development in other areas (*5*), including research into various forms of network management, the network operation has functioned without subsidy since that time.

A graph of NERComP's growth is shown in Fig. 3 together with a curve depicting growth of network revenue at a rate of 50 percent per year, which had been our initial anticipation. As Fig. 3 indicates, actual growth has somewhat exceeded this aim and has occurred in spite of an intervening cutback in federal funding for research and the increasingly uncertain nature of academic budgets and the economy. While break-even operation occurred at about $15,000 in monthly revenues, network income is now about twice this amount and is predicted to reach $40,000 per month when several additional services are introduced next year. NERComP has therefore achieved solely from networking revenues a scale of operation comparable to that of a medium-sized computing center. NERComP's experience demonstrates that a financially self-sufficient distributive network is possible, even on a regional basis with limited communication technology.

Operating Experience

While NERComP has purchased computing service from its suppliers on a per port basis, two types of basic service have been provided to users: connection by the hour at an incremental price, and a fixed-price monthly contract for unlimited hourly connection to a port. Of the two, the latter has proved more important to NERComP's success in reaching cost recovery operation. More than two-thirds of current income results from provision of service in this form. Hourly service was added only reluctantly and coincided with our recognition that there were two different audiences to be served by networking services. It is therefore surprising to us that some computer centers, including a number of national suppliers, have not recognized this market and included an unlimited-use option in their network offerings. In areas of heavy terminal utilization with low central processing unit demand, such as computer-aided instruction (CAI), the unlimited-use option would seem essential for reaching a sizable number of students.

In contrast to the fixed-price contract, the hourly pricing policy adopted by NERComP has become very detailed with time. Major components of service, including installation charges, modem costs, connect time, and storage, are now billed separately on a metered or as-rendered basis. With both policies, we have sought to establish rates independent of the distance between supplier and user, the current objective being rates less than $2 per hour or $200 per month per terminal on a contract basis for low-speed data transmission (10 and 30 characters per second) anywhere in the New England region. The resulting pricing policy can therefore be characterized as "cost recovery" only in the aggregate.

In reviewing the base of usage which has evolved during the 4 years of NERComP's operation, two significant and related factors emerge. Figure 4 shows the profile of network usage for a 1-month sample period in 1974. While this plot shows the customary few users consuming a large part of the resource (terminal time), there are some quantitative differences between the NERComP data and the data of its supplier, Dartmouth (*2*). For instance, 20 percent of Dartmouth's users consume about 80 percent of total terminal time, while the upper 10 percent consume approximately 65 percent of the terminal time. For NERComP approximately 60 percent of terminal time (range, 50 to 63) is consumed by 20 percent of the users, and only 30 percent (range, 26 to 34) is consumed by the upper 10 percent, which shows considerably less

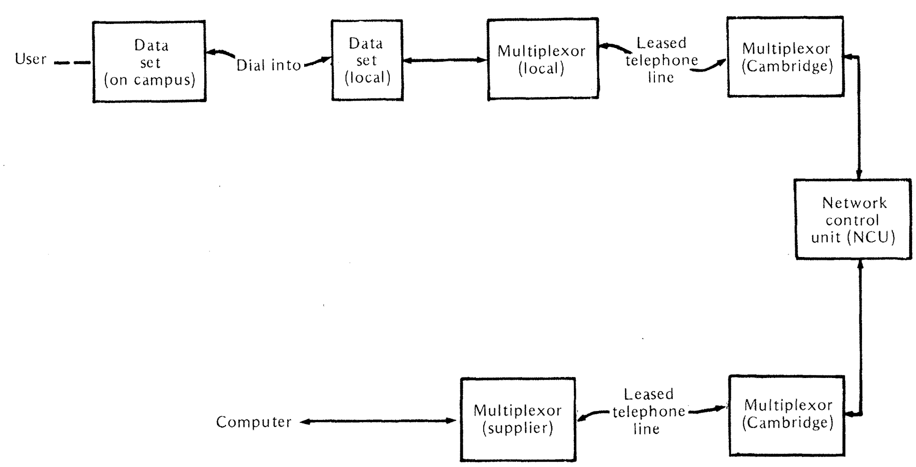
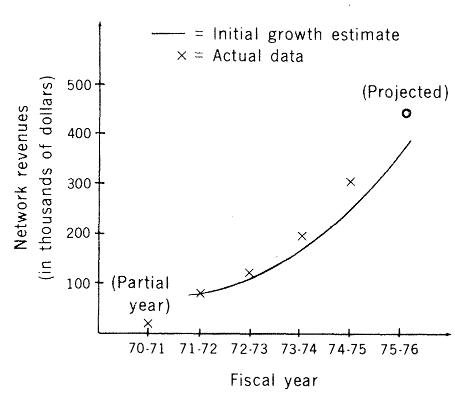


Fig. 2. Users access the NERComP network through a series of electronic devices which allow several communications to travel through leased telephone lines simultaneously. A central network control unit located in Cambridge, Massachusetts, allows the user to select the computer he wishes to utilize.



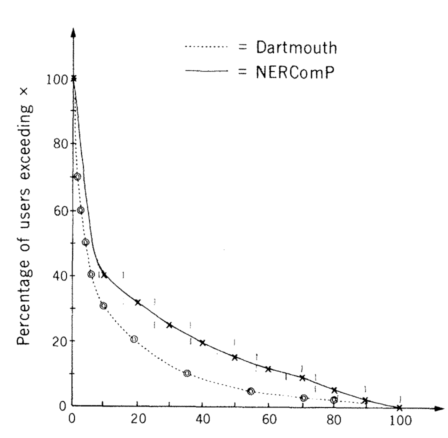


Fig. 3 (left). Network usage revenues for each year of operation since the 1970–1971 academic year. For comparison, an initial growth estimate of 50 percent per year has been included; the network has exceeded this in each year of its existence. The datum for 1970–1971 is based on a partial year, while the projected revenue for 1975–1976 relies on the 50 percent growth estimate applied to the value of the current year. Fig. 4 (right). Terminal usage of both the NERComP network (approximate) and the Dartmouth Time Sharing System. The horizontal axis indicates the percentage of total terminal time used while the vertical axis indicates the percentage of users using more than that amount. Brackets indicate the range of accuracy of the estimated values.

dedication of resources to the largest users. Thus, even if the necessary financial arrangements could be made, we are less inclined than Luehrmann and Nevison (*2*) to conclude that a policy of free access would be advisable for our network, even though it has obviously worked for Dartmouth. However, as distributive-type networking expands, the way is simultaneously cleared for individual centers to specialize in meeting the needs of their largest users.

Also of interest is the type of service these users are requiring of the network. All of NERComP's service is related to education or research. About one-half is general-purpose computing, and the remainder is largely dedicated to library programs, special packages, data bases, and CAI. There are apparently two reasons for this: (i) many users come from schools having little or no on-campus computing capability and hence must meet nearly all of their needs from the network, and (ii) where in-house facilities exist many users seek greater variety even in common services than is provided by any single center.

That this broad-based, general type of usage has developed may be surprising to those who see networks as tools for meeting specialized interests. Our experience with a regional facility suggests that an economical, distributive network will attract usage of a very general nature if this is not actively discouraged. Networks appear destined to play an unglamorous but important role in the delivery of basic academic computing service—a distribution need not well addressed in the literature.

Tax Status for Networking

NERComP evolved from computing activities initially centered at MIT and has, therefore, known both the advantages and disadvantages of being linked to a single center. In ultimately selecting a neutral location for operations together with an organization consisting of a number of equal members, NERComP was following the example of Triangle Universities Computation Center (TUCC) in North Carolina as well as that of other networking organizations (*6*). We deemed separation from any existing institution to be necessary if we were to be perceived as an independent entity able to deal with all members equally. Yet it brought with it a problem that could seriously restrict regional or national networking as a means of obtaining educational computing goals.

The Internal Revenue Service has resisted exempting consortia of tax-exempt organizations under section 501(c)(3) of the Internal Revenue Code. Thus exemption, which is important to attract the full attention and support of participating institutions and to allow the traditional benefits of freedom from taxation on purchases and income, has been obtained only through special legislation (the Common Fund, an interuniversity service organization offering advice on portfolio management to member institutions, was so exempted) and several narrow revenue rulings which have imposed severe operating restrictions.

In NERComP's case (*7*), which may set a precedent for academic computer networks, the price paid for exemption was exclusion from the network of all administrative computing—a trend recently reinforced by an unfavorable IRS ruling involving an exemption application of a consortium of state colleges in Illinois dedicated to meeting administrative computing needs (*8*).

In short, under current tax rulings educational networks could not supply administrative services such as class scheduling, billing, or processing of admissions or management information and remain exempt. Such networks might also be more generally challenged on their relatedness to the exempt educational purpose of their participants. Nor is the problem alleviated by using a (nonexempt) commercial networking carrier of the type now coming into existence because individual institutions acting as suppliers on such a network might be regarded as being engaged in unrelated business, a troublesome possibility if networking revenues become significant. Congressional relief is needed or much of the potential benefit of networking as a means for distributing academic computing resources nationally may be lost.

Networking Problems: An Overview

The use of voice-grade telephone lines employing frequency division multiplexing has limited NERComP to slow or medium-speed terminal-oriented usage. This has precluded any significant file transfer capability between computers on the network or other applications requiring computer-to-computer communications. In spite of these limitations, most members have been able to use this service as NERComP concentrated on the difficulties of networking with low-speed lines, while planning for the future. We now see that these limitations were a blessing in disguise because they allowed us to concentrate on terminal-oriented service before tackling the much more difficult problem of computer-to-computer communication. Before giving the techniques now being employed to meet this new challenge, we summarize the problems encountered in providing our original service.

1) The initial problem NERComP encountered was competition with its suppliers. By the time NERComP became operational, a number of subregional nets were already in existence supplying services from these institutions. Thus, in efforts to bring the computing services of all network suppliers into an area NERComP usually ran into competition with the nearest supplier attempting to establish its own pattern of usage. This competition was strongest, of course, on the campus of the local supplier, where network usage could be directly controlled. But it reached as well to the smaller academic institutions in the same locality, where the user was required to make a choice about who would serve his needs.

2) Allocation of computing funds between on-campus and off-campus suppliers complemented this factor in limiting initial growth. "Funny money," the term applied to departmental computer budgets which could be spent only in support of the on-campus computer center, was often a factor in making it difficult for an individual faculty member or department to purchase off-campus network services. If the institution was a NERComP supplier, this factor was an element in the competitive equation mentioned above. Research projects, which were usually independently funded, generally fared better in this regard than academic departments.

3) Network services often provided a stepping-stone to an on-campus system. No problem was more demoralizing to the staff or threatening to the early economic stability of the network than to have users disappear—often against their will—because network usage had reached the point where some kind of local computer could be justified.

4) A final problem was that network users frequently come last in the provision of services from a supplying center. This is the problem that Massy (*3*) refers to as the "organizational distance between decision-makers . . . and academic users on individual campuses." While this phase was used in reference to a computer utility, the problem is found in an even more severe form in a distributive network if one is stressing cooperative rather than competitive solutions to networking problems. It includes failure to involve remote users in local planning efforts and frequently results in the loss of users through no direct fault of the network.

In the usual single-supplier network, revenue from remote usage is usually added to an already existing base of service as a secondary rather than primary source of income. For a distributive network such as NERComP's, attaining a critical level of usage to support its operation is, of course, a primary problem.

That NERComP was able to support the network occurred largely because it was able to identify a group of users from large and small institutions whose needs were not being met and who had control over their budgets. We have also found that institutions which acquired an in-house computer under the circumstances described under problem 3 above often came back to NERComP as their subsequent experience revealed considerable unmet needs. This has led to the realization that institutional use of a network is often oscillatory, with the network complementing the growth of local computing facilities. Networking offers a good beginning service for a growing institution and allows it to build from no utilization through several steps of machine acquisition, with remote sources supplying the unmet needs before each transition. With each successive purchase, increased dependence of individual departments on the growing central facility typically results, followed by a period of administrative relaxation in which network services are more easily procured. Through this process, however, increased utilization of networking services usually occurs until the institution eventually reaches computing maturity, having acquired the largest system it can reasonably support. It is then ready to look for the satisfaction of additional needs by both buying and selling various types of computing services through a network—that is, by "trading."

By appealing to the many smaller institutions in the region that seek computer resources, we have avoided the initial heavy reliance on striking a proper balance of trade among larger networking institutions experienced by the Michigan Educational Research Information Triad (MERIT) (*9*). Enough demand has now resulted that the larger computing institutions interested in participating in the network as both buyer and seller face an almost guaranteed favorable balance of trade. While this has helped to break down the barriers to usage of the network on their part it nonetheless remains true that the inclination of most large computer-owning institutions is to sell—a condition that NERComP has sought to work with by trying to arrange paired trades. As a recent example, a group of MIT users are obtaining Dartmouth time-sharing service in exchange for that institution's usage of the MIT facility for a number of applications involving heavy computational loads.

Network Organization: The Three Network Concept

Most of the problems that arose in the course of the network's early development, including those outlined above, were a consequence of attempts to plan for rather than with those who had a stake in the outcome. Figure 5 shows the organizational structure NERComP has adopted over the last year to address the need for broad acceptance of network concepts by all member institutions. The new NERComP organization was inspired by the EDUCOM (Educational Communications) general working seminars in 1972–1973, which distinguished three types of networks within a general-purpose network (*10*). For our purposes we identify these as a governance network, a user services network, and an operating network. As shown in Fig. 5, our implementation of this concept results in an organization that differs from that described earlier by the addition of three institutional advisory committees—one for each of the subnetworks—each with a NERComP staff coordinator.

Thus NERComP is using a tripartite model not only to describe, measure, and evaluate network management concepts but also as a structure for the solution of networking problems. By adopting this network concept NERComP has selected a structure which explicitly recognizes the distributed nature of the governance and user services functions.

The Organizational Governance Advisory Committee (OGAC) is the key committee in terms of its personnel and responsibilities. Its membership includes the computer center directors at the supplying institutions, and its responsibilities include advising the board of trustees with regard to the major issues of network organization. While formally charged to develop the intersupplier arrangements related to services available, access, security, billing, and pricing policies, OGAC is emerging also as a "network market" for computer-to-computer resource sharing. The MIT-Dartmouth trade mentioned earlier resulted from these OGAC meetings, and is being monitored by this committee insofar as its organizational issues are concerned. We have found this committee to be the first in order of importance. Its early formation allows it to deal with issues which are basic and which demand resolution before other activities, such as user services, can be focused.

The User Services Advisory Committee (USAC) is composed of representatives of all the suppliers and a number of the users. Formed to develop a plan for remote distribution of user services—including training, documentation, and consultation—USAC is also developing an interesting ancillary function as a "consumers' union" where network users for the first

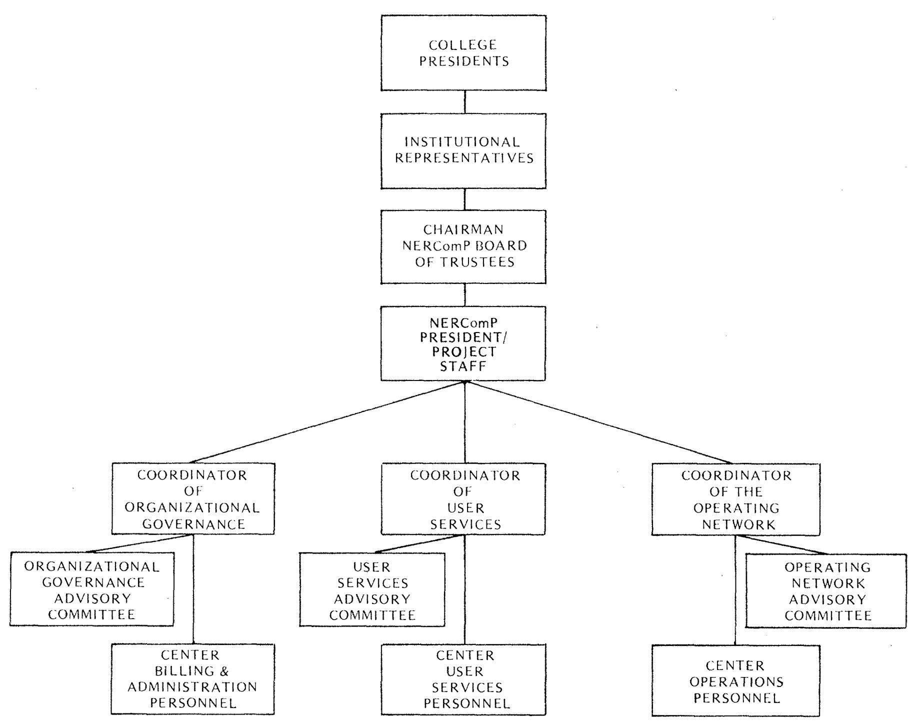


Fig. 5. Organization of the NERComP project into three separate parts for each of the major networking functions (governance, user services, and operations). Each part consists of a staff coordinator and an advisory committee made up of representatives having related responsibilities in the institutions supplying, or utilizing, the network.

time have the opportunity to gather collectively and present their needs to network suppliers. It is also a place where users can educate each other, and this is probably more important than any other activity in the long run. As with the OGAC, this committee also seems destined to serve as a market where buyer and seller meet. We expect that in time computer-to-computer exchanges will increasingly occupy the attention of OGAC, while NERComP's traditional terminal-to-computer usage is likely to receive substantial guidance and stimulation through the activities of USAC.

The Operating Network Advisory Committee (ONAC) is responsible for the design and operation of the physical network. While it is usually the least visible of the three committees (if everything is working correctly), it is now the center of activity for the technical design of a new message-switching network under development by NERComP (*11*). Its membership consists of leading technical people from each of the network suppliers. ONAC has responsibility for developing network interface standards and the several levels of protocols which are necessary to maintain communications among the various terminals and host computers in the network.

All of these committees are advisory to the board of trustees, which remains the major vehicle through which the representatives of the member institutions exercise formal control over the organization.

Resource Chaining

During much of its earlier network development, NERComP felt that it was dealing with too many problems at too great a distance and with people at too many different levels of computer sophistication. In particular, NERComP felt a growing need to decentralize both marketing of network capabilities and delivery of user services. It also became clear that a network—even a regional one—ultimately grows beyond the point where all participating institutions can relate to each other in the same way.

NERComP therefore began to explore ways to subdivide its network enterprise to maintain effective communication and to provide locally many of the services that are difficult to deliver at a distance. A view of how this might be done resulted from (i) efforts to organize a statewide network in New Hampshire; (ii) the success of the Academic Computing Group (ACCOMP), of which one of us (R.W.C.) was also a founder; and (iii) the existence of already organized networks at Dartmouth College, the University of Massachusetts, and several other NERComP supplying institutions. These experiences taught us that certain groupings of schools (often of approximately similar size and capability) were forming naturally to meet computing needs. These groups had the advantage of small numbers, perhaps a history of planning cooperative experiments in other areas, and geographical proximity. They often provided a sufficient base to either purchase a computer or link to a network or both. ACCOMP is a case in point. Having purchased a small time-sharing system in 1970 to meet a major part of the computing needs at Simmons, Babson, Regis, Curry, and a number of other colleges in the Boston area, the consortium then began to search for ways to meet the remaining computing needs of its members. This has included continuing interest in network connections.

As NERComP learned to work with the computer centers at its major supplying institutions, it seemed natural to build on rather than to compete with these smaller groups. As it turned out, the efforts to work with each of these basically different kinds of suppliers of computing service reinforced one another, as the smaller consortia often allied themselves with a larger institution in their area to obtain access to resources not available on their own equipment, if they had any.

From these antecedents grew the concept of "resource chaining" as a framework for developing a distributive network (*12*). It offered a chance for the network to decentralize operations by providing a diverse structure through which to diffuse user services and marketing. The term itself refers to the chain of institutions through which computing resources pass from supplier to distributor to end user. In short, we found in our region that a hierarchical pattern was emerging with a number of distinct levels of participation. For the sake of simplicity we have indicated these levels as follows (*13*):

1) Regional coordinator (NERComP).

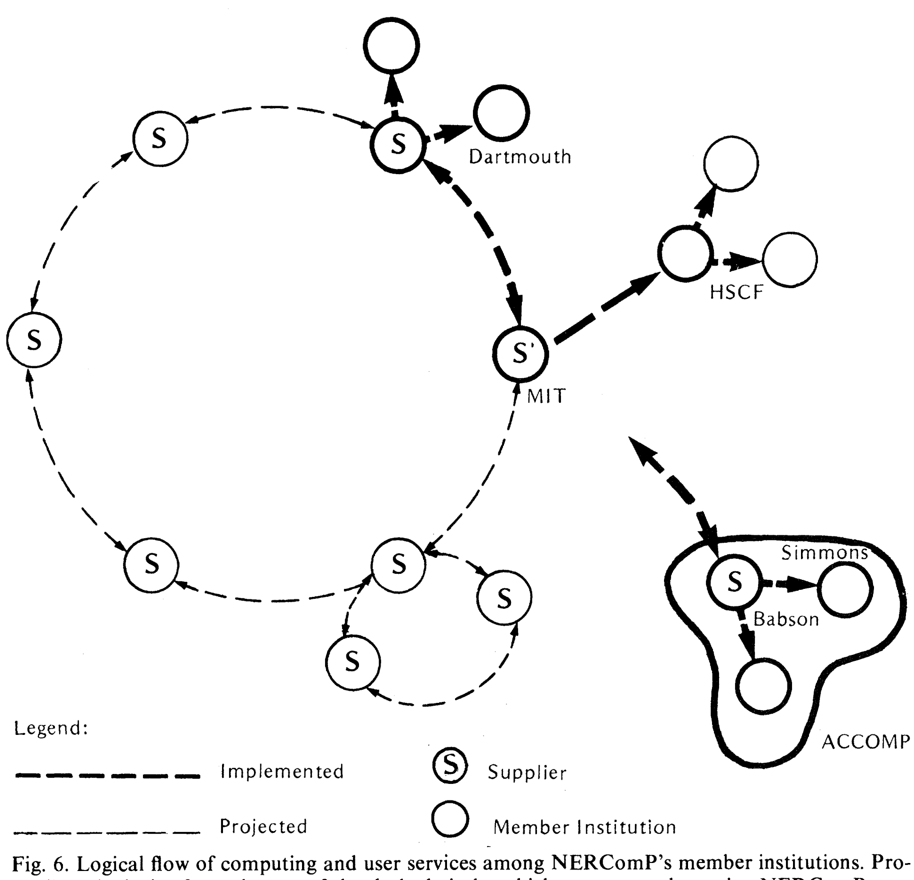


Fig. 6. Logical flow of computing and user services among NERComP's member institutions. Proceeding clockwise from the top of the dashed circle, which represents the major NERComP supplying institutions, Dartmouth is seen in its traditional role as a time-sharing supplier. Next shown is its two-way linkage to MIT, through which services are mutually distributed to users in both communities. One institution accessing the network through MIT is the Health Sciences Computing Facility (HSCF) at Harvard, which redistributes services to its medical community without itself being a network supplier. The ACCOMP group centered at Babson supplies services to its own community of colleges and is positioned to act as a secondary supplier while redistributing network services. Finally, the grouping at the bottom of the circle hypothetically shows the hierarchical concept of resource delivery evolved to an entirely new level with two redistributors with computers, each sharing services as well as supplying to the network through a nearby institution. Service connections between nonadjacent supplying institutions on the circle have been omitted for simplicity.

2) Area resources (Dartmouth, MIT . . .).

3) Local resources (Harvard Health Sciences Computing Facility, Babson . . .).

4) End-user institutions (Simmons . . .).

In this ordering NERComP, as the regional coordinator, provides a physical network facility while coordinating the primary network suppliers. These major suppliers, who are spread out and provide geographic coverage of the region, act as distributors of network services in their own areas of New England and are therefore referred to as area resources. They may interact with the end-user institutions either through redistributing institutions (local resources) or directly. Thus, NERComP's major suppliers are also distributors of computing services originating at other institutions; they provide a variety of different services more locally than could be provided from NERComP. The redistributor institutions may or may not possess small computers of their own, but they are counted on for even more localized redistribution of services. For any single network service the resource chain takes the form

Supplier → distributor → (redistributor) → end user

where the distributor is, in fact, another network supplier elsewhere in the region, and a redistributor may or may not be present.

A number of comments are in order. First, the resource chaining concept does allow institutions to alter their role as their ability to supply computing is altered. Second, the structure is independent of the physical network configuration, which results from reliability and cost considerations. Third, resource chaining implies that institutional computing centers exist to supply computing services and not necessarily to operate machinery. The term "information processing center" has now replaced the term "computer center" at many institutions. Perhaps an even better concept for the future is "center for the management of information processing resources," which is broad enough to cover both the operation of on-campus computer facilities, where they are cost effective, and the purchase of network services where they are not. Finally, the terms "area resource" and "local resource" refer only to the role of the institution in the distribution of resources through the network and are independent of other roles they may play. For example, both Dartmouth and MIT are each regional and national computing resources, apart from the role they may play here.

The complete distribution concept is illustrated in Fig. 6, which shows the steps NERComP is now taking, through OGAC and USAC, to reorganize its network. Such a structure, a generalization of the wholesaler-retailer concept (*14*), has some obvious consequences for charging, billing, and accessing the system:

1) Costs for a particular service to the end user will be assessed independently of where he enters the network. This requires that the supplying centers realize that service provided to a network costs them less than on-campus service, because they have reduced contact with end users. This difference provides a source of funding for both the actual cost of network communications and the remote provision of user services. Typically, 10 to 20 percent of the end user's charges will be available to the nearest distributor or redistributor for the provision of user service. (In some cases users prefer to access the network not through the nearest major node but through a more familiar institution. In these cases they will be assessed an additional charge based on the cost of providing the additional communications, but will be billed the same charge for user services.)

2) Accessing the network will also be controlled by the distributor or redistributor who is providing the service to the end user. It will be his responsibility to make sure that the user is authorized to access both the network and the computer center from which he wishes to obtain service.

3) Billing will occur from supplying center to NERComP to distributor or redistributor, with each institution adding on its appropriate value-added charge. Collecting the bill is the responsibility of the distributor or redistributor, which can limit its liability to an amount authorized in setting up the user account provided the supplier supports such a procedure. This system also requires that billing from the supplying center and NERComP occur with little delay, which is possible since most supplier institutions have computerized billing systems. Facilities are being built into the new NERComP network to expedite this cross-network billing process.

The resource chain concept can influence planning and is a model against which to compare the actual developing organization. By keeping the provision of computing service (whether generated locally or over the network) in the local area, subregional planning is encouraged, and existing relationships are strengthened.

In the same way existing regional networks, such as NERComP, may well offer a practical way to provide an intercomputer, interinstitutional national network. The alternative—educational and research networks which attempt to provide broad national service without relying on existing regional networks—would ignore a considerable body of experience (*15*) and would be likely to wind up repeating our own learning experiences. To us, national networking implies a hierarchy of resource delivery (a resource chain) with the regional network as one link: it would evidence all of the patterns of resource distribution illustrated in Fig. 6.

At the communications level the incorporation of these existing networks will require developing flexible "gateways" (*16*) to convert between the communication protocols, character sets, and message formats of whatever national carriers are adopted and those of the regional networks. This appears to be the only missing technical innovation needed for a national network to evolve from existing regional networks.

NIMPH Development

One task of ONAC warrants special attention because of its importance to NERComP's current development effort: the Network Interface Message Processing Host (NIMPH) computer. NERComP is modifying its current line-switched network to a message-switched network. In the latter multiple communication lines are utilized between the various network nodes, and computer-originated or -destined messages (typically one line of information) are routed from one node to another to reach their ultimate destination. This is accomplished by means of codes stored in the header of the message which are recognized by a special message-processing computer at each site.

The specific factors forcing the change to a message-switched network are: (i) the poor reliability of existing communication circuits and related equipment; (ii) the cost of multiplexing and the resulting inefficient use of communication lines (less than 5 percent of the bandwidth is being used); (iii) the lack of error correction capability in the existing network, which frequently results in garbled transmissions; (iv) the need for increased flexibility in connecting users to distant computers, including the capability for a single user to make multiple network connections; and (v) the need for increased reliability through decentralization; the system should be "fail-soft" or capable of failing in such a way that local failures in lines or switching equipment have only local consequences.

Because the NERComP network includes many small institutions, it has been clear for some time that the particular message-switching technology employed in the Advanced Research Projects Agency

(ARPA) network (*17*) would be too expensive for NERComP and its members unless substantial reductions in costs were to occur. As a result, NERComP has targeted a cost of $10,000 for the basic message-switching computer (NIMPH) which would be employed at a typical member installation. Initially we planned to use minicomputers as NIMPH's, but we could not find a minicomputer having the proper capabilities for $10,000. The resulting search to find a way to configure the network has led NERComP to consider microcomputers.

The design now being constructed (a central microprocessor for message switching with optional peripheral microprocessors for each of the interfaces: asynchronous for terminal handling, synchronous for line control, a host interface for connection to a network computer, and possibly interfaces to other peripheral devices such as a line printer and a card reader/punch) is modular, hierarchical, and one which can be tailored to the needs at each installation. The NIMPH incorporates in a single device host interface and message-switching and terminal-handling capabilities as in the ARPANET terminal interface message processor (TIP).

By using microcomputers to construct a cheap but reliable network operating over standard voice-grade lines (modulated to operate at 9600 bits per second), NERComP hopes to produce a low-cost message-switching system based on the emerging large-scale integration (LSI) circuit technology which could provide network capabilities in areas of the country where traffic requirements do not now warrant installation of TIP-devices and where the cost of line speeds of 50,000 bits per second or more is not justifiable.

Summary

After 4 years of operation the NERComP network is now a self-supporting success. Some of the reasons for its success are that (i) the network started small and built up utilization; (ii) the members, through monthly trustee meetings, practiced "participatory management" from the outset; (iii) unlike some networks, NERComP appealed to individual academic and research users who were terminal-oriented and who controlled their own budgets; (iv) the compactness of the New England region made it an ideal laboratory for testing networking concepts; and (v) a dedicated staff was willing to work hard in the face of considerable uncertainty. While the major problems were "political, organizational and economic" (*1*) we have found that they can be solved if the network meets real needs.

We have also found that it is difficult to proceed beyond a certain point without investing responsibility and authority in the networking organization. Conversely, there is a need to distribute some responsibilities such as marketing and user services back to the member institutions. By adopting a modest starting point and achieving limited goals the necessary trust and working relationships between institutions can be built. In our case the necessary planning has been facilitated by recognizing three distinct network functions: governance, user services, and technical operations. Separating out the three essential networking tasks and dealing with each individually through advisory committees, each with its own staff coordinator, has overcome a distracting tendency to address all issues at once. It has also provided an element of feedback between the end user and the supplier not usually present in networking activity.

The success of NERComP demonstrates that a distributive-type network can work. Our experiences in New England—which, because of its numerous colleges and universities free from domination by any single institution, is a microcosm for academic computing in the United States—indicate that such networks are best structured in a hierarchical form. This suggests that national networking should be based in part on the more than 30 existing state and regional networks (*15*).

With the groundwork now laid, we expect to see links among existing regional networks to complement development efforts now occurring at the national level. With Greenberger and others, we believe that one or more networking organizations devoted to the management issues discussed in this article will be required to facilitate resource sharing on a national scale. Because of their experience with these problems and their ability to provide service in many areas of the country through existing facilities, regional networks have a major role to play.

Afterview

The problem of motivating active institutional participation in viable cost-recovery networks is receiving substantial attention at both the regional and national levels. Knowledge concerning management of these network facilities and their benefits should grow as current experiments are completed (*18*) and use becomes more widespread. In our region we expect to see continued growth of our "traditional" network service—educational and research computing—complemented by increased networking among libraries, through organizations such as the New England Library Information Network (NELINET) and the Northeast Academic Science Information Center (NASIC), which provide online library services including cataloging and bibliographic search and retrieval assistance (*19*). We also expect that computer networks will play an increasingly important role in hospital and community health center settings, primarily to help meet the need for better continuing education facilities through computer-aided instruction.

The growth of networking has now produced a need for increased cooperation among networks, whether computational or informational in character, or regional or national in scope. Examples occur wherever computer and informational networks operate in the same area, as well as where links between existing regional networks or between regional and national facilities are contemplated.

As with earlier "intranetwork" development involving institutional-network relationships, issues in the areas of governance, user services, and technical operations need study for networks to cooperate effectively. For instance, how do two networks sharing the same physical resource manage it for the common good? This occurs when, say, a computer network and an informational network in the same geographic area seek to use the same communications facility. What new problems arise when the distribution chain employed in delivering a service through a regional network is extended to a national level? What communication compatibility problems arise when different computer networks attempt to "talk" to one another?

This "internetwork" problem, or set of issues which must be faced in forming network-network connections, bears considerable resemblance to the intranetwork problem. While some serious exploration has begun (*20*), a coordinated program to understand the principles of internetwork cooperation remains in the future.

References and Notes

1. M. Greenberger, J. Aronofsky, J. L. McKenney, W. F. Massey, *Science* **182**, 29 (1973).
→ A. W. Luehrmann and J. M. Nevison, *ibid.* **184**, 957 (1974).
→ W. F. Massy, *ibid.* **186**, 414 (1974).
4. The terms multisupplier, multinuclear, ring, and distributive have all been used to describe the type of network under discussion here. Similarly the terms single-supplier, nuclear, star, computer utility, or more simply time-sharing network all appear in reference to a communications network supplied from a single computing center. We prefer multisupplier or the term distributive network as used by Massy (*3*). The use of the terms ring and star in this context is, in our judgment, unfortunate, as these terms relate to network topology

rather than the breadth of the services provided and encounter the further ambiguity that a distributive network may employ a starlike topology (see NERComP's current network depicted in Fig. 1).
5. The NERComP's research and development activities are currently funded by the Control Data Corporation and the National Science Foundation.
6. I. W. Cotton, *Natl. Bur. Stand. Tech. Note 805* (1974), p. 34.
7. Revenue Ruling 74-614, *Intern. Revenue Bull. No. 52* (1974).
8. "State-college consortium denied tax exemption," *Chron. Higher Educ.* (16 December 1974), p. 7.
9. B. Herzog, *Compcon* **73**, 11 (1973).
10. M. Greenberger, J. Aronofsky, J. L. McKenny, W. F. Massy, Eds., *Networks for Research and Education: Sharing Computer and Information Resources Nationwide* (MIT Press, Cambridge, Mass., 1974). This reference also includes a discussion of the NERComP network organization at an earlier point in time. See T. E. Kurtz, "The NERComP network," p. 282. NERComP's exploration of governance, user services, and operating network structures has been undertaken with the assistance of the National Science Foundation.
11. The term "packet-switching" is often used to describe a network of the type under discussion here in which information is transmitted in blocks of limited size with origin and destination address codes included to control forwarding of the block to the proper host computer and the return of the appropriate response. We prefer the generic term "message-switching" in this context, which leaves open the question of how the message is "packetized" or broken down into smaller units for transmission. For an excellent discussion of these terms see the Final Report of the Ad Hoc Group on Packet Switching, "Study of areas for standardization in packet switching," American National Standards Institute (ANSI) Task Group X3S37 Document 75-10, 7 February 1975. I. W. Cotton, Chairman.
12. R. Ricard, former institutional representative from the University of New Hampshire and current chairman of OGAC, is responsible for the resource-chaining concept as applied to computer networks.
13. The terms used here were inspired by those used by the Regional Medical Library Program for the distribution of medical materials through the interlibrary loan system, administered by the National Library of Medicine. See H. M. Schoolman, *Bull. Med. Libr. Assoc.* **60** (No. 2), 284 (1972); V. Pings, *ibid.*, p. 274.
14. D. L. Grobstein and R. P. Uhlig, *AFIPS (Am. Fed. Inf. Process. Soc.) Fall Joint Comput. Conf. Proc.* **41**, 889 (1972).
15. F. W. Weingarten, N. R. Nielsen, J. R. Whiteley, G. P. Weeg, *Study of Regional Computing Networks* (Univ. of Iowa Press, Iowa City, 1973); C. J. Mosmann, *Statewide Computing Systems: Coordinating Academic Computer Planning* (Dekker, New York, 1975).
16. G. Marks of the Institute of Social Research, University of Michigan, first called this term to their attention.
17. L. G. Roberts and B. D. Wessler, *AFIPS (Am. Fed. Inf. Process. Soc.) Spring Joint Comput. Conf. Proc.* **36**, 543 (1970).
18. EDUCOM has planned a simulation and gaming project in which key administrators at approximately 15 leading academic institutions will participate in the formation of a national network model, then play a game designed to show the probable effects on their institutions over a period of years of various decisions regarding network participation. This program complements many studies carried out by existing regional consortia, including NERComP, over a number of years.
19. Both NELINET and NASIC are programs of the New England Board of Higher Education.
20. The Council for Computerized Library Networks, consisting of approximately 15 leading organizations in the area of application of computers to library networking, has recently formed to "identify, discuss and coordinate solutions to common problems." Its current interests include the internetwork governance issue.
21. The NERComP board of trustees consists of: Thomas E. Kurtz (Chairman of the Board), Director, Kiewit Computation Center, Dartmouth College; Philip M. Morse (Vice-Chairman of the Board), Director, Operations Research Center, Massachusetts Institute of Technology; John Alman (Secretary), Director, Computation Center, Boston University; Edgar T. Canty, Director, Computation Center, Babson College; Alan D. Ferguson, Executive Director, New England Board of Higher Education; Greydon C. Freeman, Director, Computer Center, Yale University; Walter Freiberger, Director, Center for Computer and Information Sciences, Brown University; Jeremy E. Johnson, Director, Computing and Data Processing Services, University of Maine; Norman Johnson, Director, Academic Computer Facility, Wheaton College; Raymond K. Neff, Director, Health Sciences Computing Facility, Harvard University; Roderick Ricard, Institutional Representative, University of New Hampshire; and Conrad Wogrin, Director, Research Computing Center, University of Massachusetts. Robert A. Rolla currently serves as President.

NEWS AND COMMENT

White House Science Adviser: House Committee Rewrites Its Bill

Congress is moving with all deliberate speed on legislation to reestablish a science adviser's office in the White House, but it seems unlikely that action will be completed before the traditional autumn rush to adjourn. Thus the White House probably won't be able to start talking seriously with candidates for the job of science adviser until late this year or early next.

The most recent sign of progress is a new draft bill prepared by staff of the House Committee on Science and Technology to replace the National Science Policy and Organization bill introduced earlier this year by the committee's leadership, Olin Teague (D-Tex.) and Charles Mosher (R-Ohio). On the Senate side, the three committees with jurisdiction over science advisory bills are biding their time, waiting for the House to act. Democratic leaders of the Labor and Public Welfare, Commerce, and Aeronautical and Space Sciences committees seem to regard the new House bill as workable, although there is some feeling that it needs strengthening. A spokesman for Senator Edward Kennedy (D-Mass.) said, for instance, that, while the bill was generally commendable, sections detailing national science policy and duties of the science adviser seemed unnecessarily fuzzy and rhetorical.

The new House draft, dropped in the hopper just before the August recess began, is an amalgam of the original Teague-Mosher bill and a very brief bill drawn up by the White House (*Science*, 6 June and 4 July). As expected, the committee has discarded its proposal for a council of science advisers in favor of the lone science adviser and a small staff favored by President Ford. In a revival of a requirement placed on former science advisers, the new one, in his capacity as director of the White House Office of Science and Technology Policy, would be subject to Senate confirmation. Ford and most, if not all, the House committee favored confirmation and the implied extra access Congress would have to the science adviser. But some of the President's legal staff reportedly had objected on the ground that Senate confirmation of White House officials served to erode executive privilege. Their arguments apparently were not persuasive.

The new committee draft lays out the duties of science adviser in more explicit detail than the Administration version's bare-bones, 70-word discussion of responsibilities. Unlike the Ford bill, the House version specifically grants the science adviser a role in areas of national security, economics, health, and environmental affairs and says that he or she "shall . . . participate throughout the budget development process." The precise relations between science adviser and other major policy units of the White House is, however, left for the President to decide. The House bill says only that the science adviser shall "develop appropriate working relationships with" the National Security Council and the Domestic Council.

At present, the titular science adviser, National Science Foundation director H. Guyford Stever, has no voice whatever in the area of national security and his leverage in domestic policy planning seems not much greater. There is, as a result, a body of opinion that the new science adviser ought to be a member of both the National Security Council and the Domestic Council if he is to have any real influence at these crucial focal points of power. The House committee, however, is trying hard to construct a science office that is acceptable to Ford and which he and other Presidents will use. And in simply specifying that the science adviser should have a role in these areas—to be defined by the White House—the committee has already gone beyond the vague job description proposed by the White House.

Like the Teague-Mosher bill it replaces, the new bill contains a long preamble set-